A 1" High Resolution Field Sequential Display for Head Mounted Applications

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Abstract:

Color displays used in binocular Virtual Reality today are generally LCD arrays, with the maximum resolution determined by how small the individual color pixel elements can be made and driven electronically. The images are highly pixlelated, especially under magnification. With present technology, the resolution is about 210 color pixel triads horizontally and 140 color pixel triads vertically for a typical display. This paper will describe a high resolution color display (640 X 480) using a monochrome CRT and a Liquid Crystal shutter operated in a field sequential color mode.

Introduction:

Consider yourself on the star ship Enterprize (the next generation) and you walk onto the holodeck to experience a totally emersed Virtual Reality computer simulation. The dialogue goes like this: "Computer, start program! *Program initialized.* Computer!, what is wrong? The objects are all blurred, the lines are fuzzy and I can't see anything smaller that a baseball! *Nothing's wrong - The program is rendered in 210 by 140 resolution.* Computer, I see what appears to be a sign, but why can't I read it? *At 210 by 140 resolution, you are legally blind and have 20/800 vision.* Computer, Can't you improve the resolution? *Not yet, the display technology of your time is not good enough to display what you anticipated."* You stumble around for a while and leave with the nagging feeling that Virtual Reality is not going any where unless the displays are improved significantly.

There is one display system that will improve the Virtual Reality displays. In a field sequential color system there are no, resolution limiting, individual pixel triads. Each complete color image is displayed on a monochrome CRT, individually in a red/green/blue sequence with a color filter in front to produce the appropiate color. This sequence of color images is repeated over and over and fast enough so the eye will merge the colors. The resolution is only limited by the spot size of the monochrome CRT, the vertical scan rate, the horizontal scan rate and the video bandwidth of the monitor. At present a 10 fold improvement in color displays can be achieved.

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Field Sequential Color

The field sequential color system has been around a long time. In 1940, CBS developed a field sequential color TV system which had a rotating color filter wheel in front of the camera and another similar wheel between the display and the viewer. See Fig 1. Both rotating color filters were synchronized, when the red filter was in front of the camera, the red filter was in front of the CRT showing a red image. The same thing happened for the green and blue filters. With the color filer wheel rotating fast enough, a full color image was generated. This system produced excellent color images, but had mechanical problems packaging a large rotating color filter wheel.

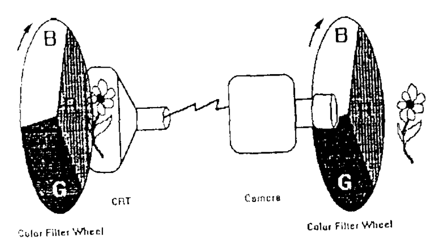

Fig 1. CBS Field sequential color TV

The Tektronix Field Sequential Color System.

To replace the mechanical color filter wheel, Tek has developed an electronic switchable color filter using color selective polarizers and a liquid crystal variable retardation device. "Color polarizers" are made with a special color dye that produce a polarizer sheet that will pass all colors of light if the axes of polarization are parallel, and only a single color when the axes of polarization are perpendicular. These "color polarizers" come in many colors and we have selected appropriate polarizers to produce red, green, and blue passing filters.

The variable retarder device is a proprietary fast switching liquid crystal device developed at Tektronix. This "Pi cell" will rotate the axis of polarization of light passing through it when it is not on, and pass the light unchanged when it is on.

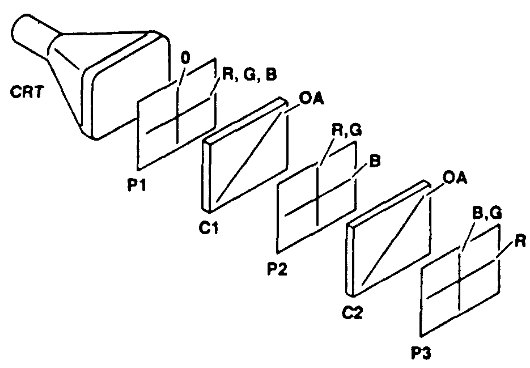

Fig 2 Tektronix Color Shutter construction

Fig 2 shows how a stack of 5 color polarizers and 2 Pi cells can be arranged to make a 3 color electronic switchable filter. The first polarizer (P1) is a normal polarizer that polarizes all colors of light in a

horizontal direction. The second polarizer (P2) is made of 2 polarizers, a horizontally oriented blue polarizer, and a vertically oriented yellow (red and green) polarizer. The third polarizer (P3) is made of a horizontal oriented red polarizer, and a vertically oriented cyan (blue and green) polarizer. When the first Pi cell (C1) is on, the horizontally polarized light is not rotated, passed through the blue polarizer and comes out as only blue light. If the second Pi cell in off, the blue light is rotated by 90 degrees, passed through the vertical cyan polarizer and exits as blue light. With C1 off, the horizontal white light is rotated by 90 degrees and passed through the vertical yellow polarizers at P2 as vertical polarized yellow light. With C2 turned on, the yellow light passes through un rotated, passes though the green vertical polarizer and exits as green light. With C2 off, the vertical polarized yellow light is rotated by 90 degrees, passes through the horizontal red filter and exits as red light. Table 1 is a listing of the states of the two Pi cells and the

C1	C2	Color
OFF (90 deg)	ON (0 deg)	Green
OFF (90 deg)	OFF (90 deg)	Red
ON (0 deg)	OFF (90 deg)	Blue
ON (0 deg)	ON (0 deg)	No Light

Table 1

resulting colors. Just like the rotating color filter wheel, the Tektronix Liquid Crystal Color Shutter can be switched to red, green, or blue in synchronism with the appropriate color image displayed on the monitor, and produce a full color image. By selecting the appropriate color polarizers and the correct blend of P45 phosphor for the monochrome CRT Tektronix has been able to closely match the color spectrum of a standard shadow mask CRT. Fig 3 shows the possible color gamut that has been achieved with the Frame Sequential Liquid Crystal Color system. Wider color gamuts are possible with other polarizers and phosphors.

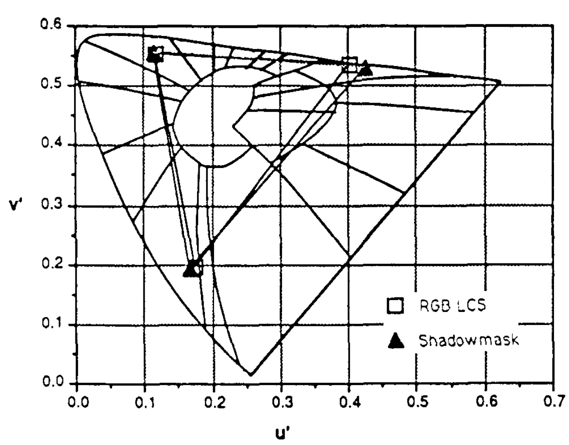

Fig 3 Color gamuts LCS vs Shadow mask

Requirements of a Field Sequential Full Color Monitor

There are several things that a normal monochrome monitor has to have improved to function as a frame sequential color monitor. Primarily, the monitor needs to run 3 times as fast. For each complete color image, the monitor needs to display a red image, a green image and a blue image. This forces the vertical scan rate to be 180 Hz in order to get the 3 color images and still have a complete color image at a 60 Hz rate. Some computer monitors run at 70 Hz vertical rate which forces a sequential color system to run even higher, at 210 Hz. For the same number of horizontal lines, the horizontal scan rate has to increased 3 times. For a 480 line image, 91Khz horizontal scan rate is required. For a given number of horizontal pixels the video band width has to be increased the same amount. For a 640 X 480 resolution image, a video bandwidth of 88 Mhz is required.

In order to present the individual color images with the specified resolution, the size of the smallest addressable pixel (the spot size of the CRT beam) has to be sufficiently small. For a 1" display measuring 0.8" horizontal by 0.6" vertically and 640 X 480 resolution the spot size has to be about 0.6"/480 or 0.0012". The spot size can be slightly larger depending on the shape of the luminance profile of the spot.

The Liquid Crystal Color Shutter uses polarizers, which by their nature attenuate 50% of normal light passing through them to produce polarized light. The color polarizers, each passing only 1 of the 3 primary colors passe only 33% of the light. With Tektronix shutter system, a maximum efficiency of 16.6% is the limit. In practice, with available polarizers and optical boding, our system is slightly over 7% efficient. This forces the CRT to provide about 800 FL to produce 50 FL out of the shutter.

All of these parameters are available or can be exceeded. The Tektronix 1" high brightness CRT has a spot size of 0.0015" with 800 FL. The vertical scan rate can multi sync from 150Hz to over 200Hz. The horizontal scan rate can multi sync from 60Khz to over 120Khz and the video bandwidth is 120Mhz. All these features can easily produce an image with 640 X 480 resolution and probably be pushed to 600 X 800. The first limitation is the spot size and the next is the video band width.

Binocular Displays

The normal implementation of a 1" color display in a Virtual Reality system would have 2 displays, one for each eye. Optics are used to magnify and focus the images. Having 2 displays that have to be merged, puts additional requirements on the monitor system. Each display has to have individual adjustments to superimpose the left eye image with the right eye image. Vertical and horizontal size adjustments are needed to make both images the same size. A viewer can not accommodate

much size discrepancy from right to left eye. In my experience, size discrepancies of > 0.2% can cause stress while viewing a binocular image. Vertical and Horizontal position adjustments are also required. Vertical position is not as sensitive but I find it should be matched to < 1%. Horizontal position differences are one of the depth ques. The horizontal position error ought to be kept small and certainly can not be divergent or to convergent. Picture rotation is also important. The rotation difference between both images ought to be kept below 0.5 degrees. In general, all aspects of each image for both eyes ought to be correct: position, rotation, size, brightness, focus, color, ETC or the viewer may experience stress, nausea, or have problems merging the images.

Optical Issues

When images are viewed through simple lenses, geometric optical distortion is introduced generally in the form of pincushion distortion. Fig 4 shows what a 7 X 9 grid looks like when viewed through a lens with about 20% geometric optical distortion. This problem becomes worse when off axis optics are used. Fig 5 show a 6 X 6 grid with off axis distortion. Generally the computer generated image is modified or pre-distorted so the image looks correct through the lenses. With the heavy burden of image rendering, the computer should be relieved from this task and let the monitor compensate for this distortion.

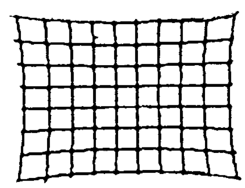

Fig 4 7 X 9 grid with 20% distortion

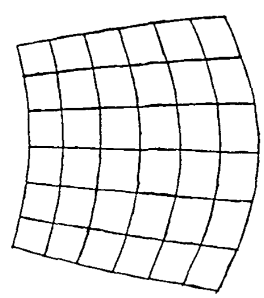

Fig 5 6X6 grid with off axis distortion

The Tektronix 1" monitor system has 4 separate adjustments in each axis to accommodate optical geometric distortion and will accommodate about 20% adjustment.

Another optical problem with achromatic lenses is that the colors in the periphery of the image don't converge. In a frame sequential color system it would be simple to dynamically adjust the size and geometry for each color independently to correct this problem.

Tektronix EX100 1" Binocular Monitor

The EX100 monitor consists of three main parts, a common central unit and two individual display units. See Fig 6. The central unit contains two identical channels, one for each eye. Each channel has a video preamp which can be used

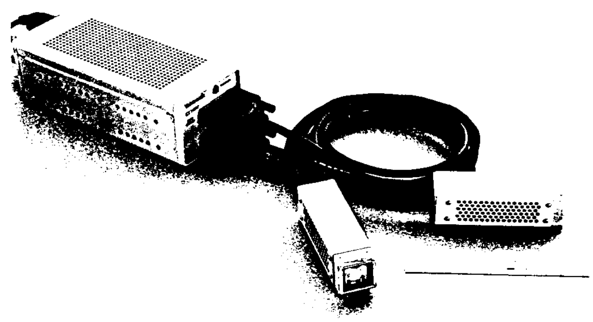

Fig 6 Tektronix EX100 Monitor and display heads

vertical and horizontal deflection circuits and complete geometric compensation circuits. The common unit contains the high voltage supply and other required supplies and is connected to each display unit with a detachable cable. Each display unit contains the circuitry for the final horizontal output, the video output and the liquid crystal drivers. The CRT, made at Tektronix, is a custom bi-potential design and has the color shutter attached. See Fig 7

The basic specifications for the EX100 are:

Video input	Frame sequential RGB or parallel RGB
Video bandwidth	0 to 120 Mhz
Horizontal rate	Multi sync 60Khz to 120Khz
Horizontal blanking	3us
Vertical rate	Multi sync 150Hz to 200Hz
Vertical blanking	400us
Sync	Sync on serial video or sync on green
Brightness	30 FL white field
Weight	7.5 Oz each display, 3 lb total unit
Size	1.25" X 1.25" X 4.75" Display 2.6" X 3.5" X 8.5" Common unit

Video Drive For The Tektronix Field Sequential Monitor.

Many 1000 line high resolution video cards will drive the EX100 system when used in the parallel RGB input mode. The video card has to support 180Hz vertical rate, 91KHz horizontal rate, and 88MHz video rate. The SPEA VIDEO 7 WIN.VGA card for the IBM computer is such a card. The supplier of the card generally offers programmers reference data for the user to write TSRs to modify the display rates.

Tektronix Inc. offers a set of two cards (WIN.VGA card and a custom serial video output card) that come with the EX100 for an IBM compatible computers. Other high end display systems can also supply the necessary video format. The Silicone Graphics Reality Engine with the Video Spliter option is an example.

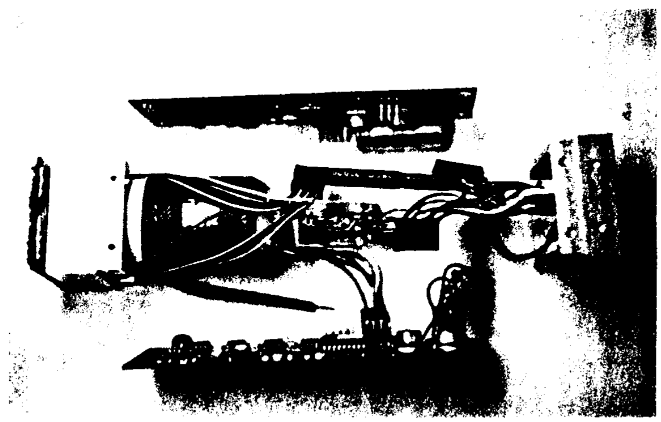

Fig 7 Display head showing CRT and ECBs

Conclusion

The Tektronix 1" frame sequential color monitor system significantly improves the resolution of color displays for Virtual Reality head mounted displays to at least 640 X 480. With larger, lighter CRTs and yokes, and higher performance monitor designs, the resolution of a frame sequential color, head mounted display could be pushed to about 1280 X 1024. As the monitors improve, so will the rest of the Virtual Reality systems. Latency will come down, rendering speed will go up, memory limits will increase ETC.

Of course the holodeck of the star ship Enterprise is only real today, for the authors and actors of Star Trek TV, but the challenge will be there for the electronic engineers of the future to conceive, refine, and fabricate - and for people to experience.